Strategies for Reducing Delamination in GaN Die Attach: Optimizing Bond Line Thickness and Die Bonding Parameters Enabled by Predictive Statistical Analysis

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ABSTRACT

The quality of the bond line, especially in preventing delamination that can occur during initial assembly, is crucial to the package reliability of die attach in radio frequency and high-performance electronic devices. Die attach delamination at zero-hour presents serious complications that affect the long-term stability and performance of the device. To comprehend how bond line morphology impacts adhesion and overall reliability, this study examines the impact of silver sinter bond line thickness on the coverage and efficacy of the die attach epoxy. By investigating this connection, the study aims to create methods for addressing zero-hour delamination problems, guaranteeing strong die attachment, and improving the production process for electronic assemblies with high reliability.

The main factors affecting bond line thickness in die attach processes are systematically identified and controlled in this paper using a design of experiments (DOE) approach. The study determines the crucial controllable parameters that directly affect bond line thickness through extensive experimentation, including dispense parameter, pressure, and time. The results highlight the significance of variability in process control by showing a clear correlation between bond line thickness and die attach delamination occurrence. The research provides important insights into reducing zero-hour delamination by comprehending and improving these factors, which will ultimately improve die attach's performance and dependability in electronic packaging.

1. 0 INTRODUCTION

To guarantee optimum performance and dependability in high-frequency radio frequency applications, the integrity of the connection between the semiconductor device and its carrier, flange, or header is crucial. Silver sintering is a popular bonding method because of its superior thermal and electrical conductivity, both of which are essential for transmitting radio frequency signals. These characteristics, however, can be seriously jeopardized by the presence of voids or delamination within the sintered joint, which could result in mechanical failure, decreased heat dissipation, and increased signal loss. For RF components to retain their electrical integrity, mechanical robustness, and thermal stability—and ultimately improve device performance and operational lifespan—a void-free and delamination-free silver sintering process is necessary.

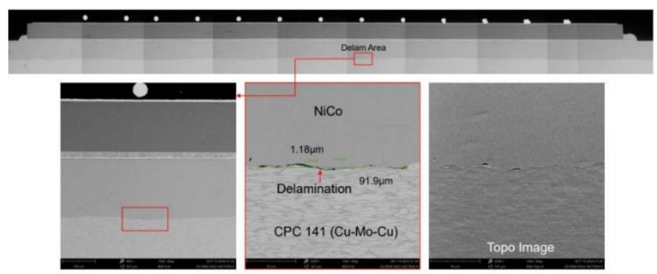


Fig 1.0 Delamination

During production, the delamination defect found in the air cavity ceramic package with GaN die has developed into a persistent issue that continuously compromises the dependability and quality of the final product. This delamination has continued and became the top defect during the initial production ramp-up, in contrast to the short-term problems observed during early development, suggesting that it is a systemic problem rather than a passing anomaly. Its recurrent nature emphasizes the necessity of thorough research into the root causes, such as material characteristics, process variables, or design considerations, to create long-lasting, practical solutions and stop future incidents in the manufacturing process.

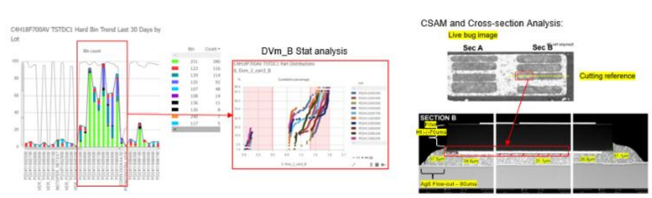


Fig 1.1 Gross DVm_B fails on DC1 Testing at 32% were

observed on 10 lots on WK2412. Statistical assessment showed double and wide distribution exceeding the USL. Initial failure analysis showed delamination in between BSM and silver Sinter.

Units with die attach delamination showed die tilting and thinning of the cured or dry silver sintering, which led to uneven and insufficient material dispersion at the interface, according to a thorough examination of the failing parts during failure analysis. Uneven pressure and distribution of the silver sinter are caused by die tilting, which happens when the die is not precisely aligned during the attachment process. Thinning of the sintering material, often due to insufficient material application or improper sintering conditions, leads to localized weaknesses and void formation. These issues create inconsistent bonding areas, reducing the mechanical integrity and thermal conductivity of the interface. These problems result in uneven bonding regions, which lowers the interface's mechanical strength and thermal conductivity. As a result, under operational stress, regions with insufficient sinter coverage are more likely to delaminate, crack, or fail.

Increasing the quantity of silver sintering material is necessary to guarantee thorough and consistent dispersion within the interface, which will address the delamination problem brought on by irregular silver sintering. Enough silver can improve coverage and filling during the sintering process, lessen die tilting and thinning problems, and encourage stronger, more dependable die-substrate adhesion. This modification will eventually improve the package's overall robustness and long-term dependability by reducing the development of voids and delamination.

2. 0 REVIEW OF RELATED WORK

1. "Void defects are a critical concern for large-area sintered silver attachment using the pressure-less sintering. Void defects must be controlled before sintering, especially during mounting devices. To minimize the void defects, some researchers designed and optimized the dispensing or stencil-print pattern of silver pastes and patterns during the dispensing process. The air bubbles of the as-dispensing paste during the mounting can be squeezed out. However, the pattern should be optimized to prevent the excess insufficient and overflowing of the nano silver paste. Moreover, the mounting accurate pressure and position should be controlled".
   P. Liang, H. Yan, W. Li and D. Yang, "Void Eliminating Process of Sintered-Silver Die Attachment in Anaerobic-Sintering Atmospheres," *2020 21st International Conference on Electronic Packaging Technology (ICEPT)*, Guangzhou, China, 2020, pp. 1-4, doi: 10.1109/ICEPT50128.2020.9202689.
   keywords: {Silver;Bonding;Atmosphere;Heating systems;Heat sinks;Copper;X-ray imaging;Void defects;Pressure-less sintering;Vacuum reflowing;Sintered silver},
2. "A virtually void free die attach was successfully achieved using a fixed but critical volume of Ag sinter paste by a process of pressure-less sintering on a multi-axis cartesian style bonder, retrofitted with a high-speed jetting dispenser. While this process potentially offered an ideal combination of cost-effectiveness, control and speed, it required the development of additional software protocols to secure the level of performance demanded of the dispenser to meet exacting technical requirements. This proprietary adaption we term "Fixed BLT" software, and over five test pieces we were consistently able to deliver a fixed height bond-line of circa 70% of bond height, translating as 50µm before sinter and 30µm after. In each case the result was a virtually bond free void secured in a timely, repeatable, commercially effective manner. The absence of voids was verified through industry standard non-destructive analysis utilizing C-mode scanning acoustic microscope (CSAM)".
   Energy & Eco-Sustainability using Pressure-less Silver Sintering for RF Power Electronics Authors: Evan A. Hueners, Richard D. Hueners, Anthony D. F. O'Sullivan, M. Redzuan Zin.

3. "Fig. 3 shows the shear strength of the joints with various BLT. It presents the shear strength linearly increased as the BLT increased from 3.5 to 60 µm . The shear strength of 60 µm BLT samples was extremely high, >70 MPa. When the BLT decreased to 3.5 µm , the shear strength remarkably decreased to ~20 MPa, which is still much higher than the requirement of MIL-STD-883K standard (~7.6 MPa).

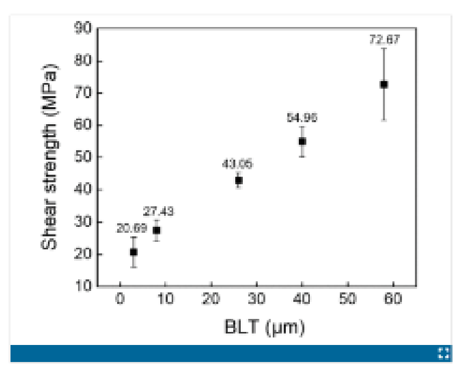


Fig. 3.
Shear strength of the joints with different BLT.

Z. Deng *et al.*, "Effect of Ag Sintered Bondline Thickness on High-Temperature Reliability of SiC Power Devices," in *IEEE Transactions on Components, Packaging and Manufacturing Technology*, vol. 11, no. 11, pp. 1889-1895, Nov. 2021, doi: 10.1109/TCPMT.2021.3110997. keywords: {Reliability;Silver;Microstructure;Sintering;Silicon carbide;Bondline thickness (BLT);nano-Ag sintering;power cycling test; pulsed laser deposition (PLD);reliability},

3.0 METHODOLOGY

The methodology for this research employs a Design of Experiments (DOE) approach to optimize bond line thickness and eliminate delamination in silver sinter die attach for GaN dies by focusing on dispense parameters, pressure, and time. The investigation of these parameters' individual and combined effects on bond quality and delamination propensity will be made possible by the design of a factorial or response surface DOE, which will systematically vary these parameters within suitable ranges. The experimental matrix will guide the silver sintering process. Process control monitoring will be used to evaluate delamination and bond integrity, and cross-sectional microscopy will be used for detailed characterization. The best mix of dispense volume, applied pressure, and time that reduces delamination will be found by statistically analyzing the experimental data.
To determine the ideal bond line thickness that guarantees full silver sinter coverage while avoiding time-zero delamination, the results of the customized full factorial DOE investigating bond line thickness and its relationship with delamination were processed using an optimization algorithm. To balance variables like dispense volume, pressure, and sintering time and produce a uniform, adherent bond with little defect formation, the optimizer examined the experimental data to determine the best process parameters. In the GaN die attach process, this method makes it possible to determine a bond line thickness that optimizes bond integrity and dependability by facilitating precise process control.
To attain a delamination free product, a thorough study has been conducted by varying bond line thickness and correlation response on DVM parameter at Test and scanning acoustic tomography (SCAT) for delamination check as shown in Fig3.0. Process window will be established using 2 factors, Overtravel and Dispense pressure as input parameters with bondline thickness as main response and acceptable fillet height and flow-out requirement. The product reliability requirement is 500cycles TMCL.

DOE Run						Main Response		Other Responses	
Leg	Run Order	Overtravel	Delay (200)	Disp Pressure (100min)	Sample Size	BLT SS	Dvm / SCAT	Fillet Height (<0um)	Flow-out (100%)
Low BLT (30-40)	1	Adjust	200	Adjust	30	Wet-10pcs Dry-30pcs	100%	Wet-10pcs Dry-30pcs	Wet-10pcs Dry-30pcs
Mid BLT (50-60)	2	Adjust	200	Adjust	100	Wet-30pcs Dry-30pcs	100%	Wet-30pcs Dry-30pcs	Wet-30pcs Dry-30pcs
High BLT (70-80)	3	Adjust	200	Adjust	100	Wet-30pcs Dry-30pcs	100%	Wet-30pcs Dry-30pcs	Wet-30pcs Dry-30pcs

Fig 3.0 Bondline Thickness Trial

During die attach, 100% coverage during set-up was targeted including corners with no crater formation on dispense path. In Fig 3.1 was the achieved target Bondline thickness with passing requirement on fillet height and flow-out.

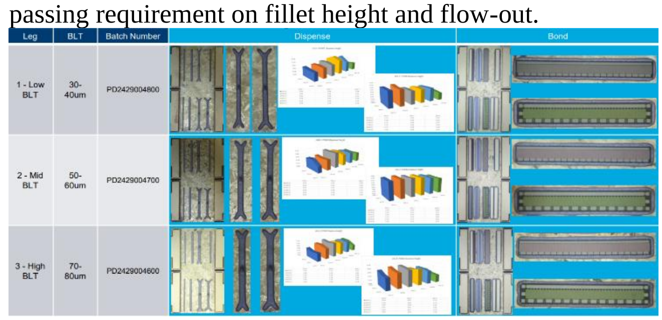


Fig 3.1 Set-up Condition on Bondline Thickness Legs

4.0 RESULTS AND DISCUSSION

The bond line thickness DOE results indicated that within a specific range, variations in bond line thickness do not significantly impact the reliability or cause shifts in the critical parameter DVM, the test parameter that is related to varying bond line thickness. A threshold below which bond line thickness is consistent with full silver sinter coverage was identified statistically, guaranteeing strong adhesion without sacrificing thermal or electrical performance. According to DOE and further analysis, the optimal bond line thickness shows that there is no discernible drop in test metrics or device reliability when this parameter is kept within the designated range. These findings confirm that a controlled bond line thickness, within the established window, will not adversely affect the overall performance or longevity of the GaN die attach, providing a reliable process window
Fig. 4.0 presents the result of a One-Way Anova on both die05 (POS05) and die06 (POS06) indicating that significant factors (Overtravel and Dispense pressure) considered in the evaluation matrix have R-sq of 97.66% and 98.24% respectively.

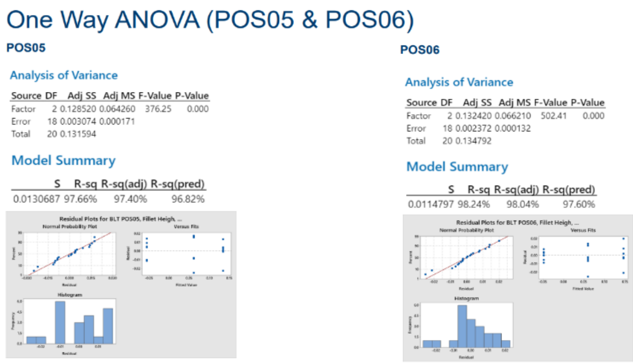


Fig. 4.0 One-Way Anova

Factorial regression in Fig 4.1 indicates that there is no interaction between 2 factors. Overtravel appears to be significant in BLT with p-value <0.05 for die05.

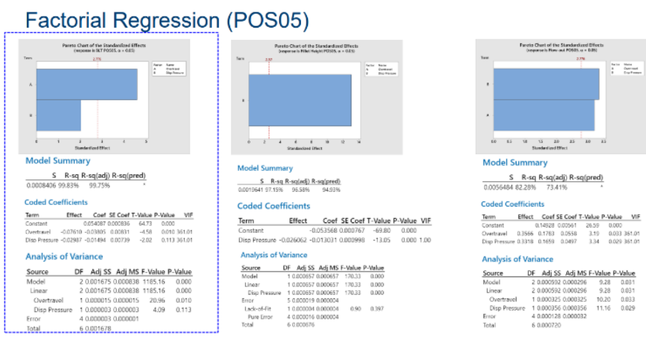


Fig. 4.1 Factorial Regression for die05(POS05)

Factorial regression shown in Fig. 4.2 indicates that there is no interaction between 2 factors. Overtravel appears to be significant in BLT with p-value <0.05 for die06.

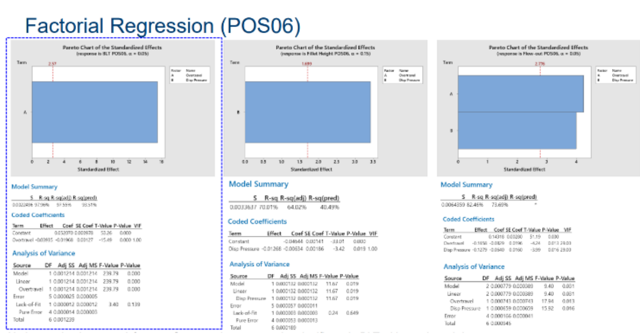


Fig. 4.2 Factorial Regression for die06(POS06)

The correlation study for Dvm_2_corr2_B shown in Fig. 4.3 indicates that this parameter is more correlated on Bondline thickness with R-sq of 90.3% than flow-out and fillet.

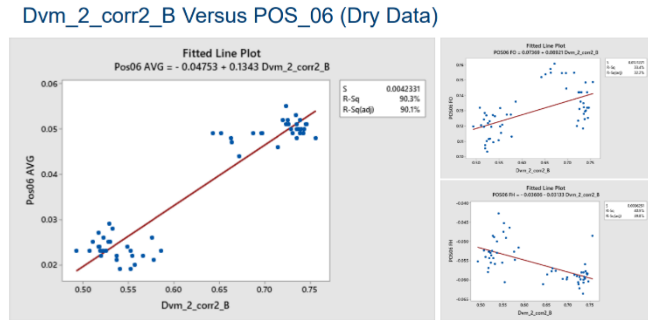


Fig. 4.3 Dvm_2_corr2_B Versus BLT

Increasing Bondline thickness as shown in Fig 4.4to 65±10um will not have significant effect on dvm specs of 0.3-0.9V. Furthermore, increasing bondline thickness improves die attach ruggedness.

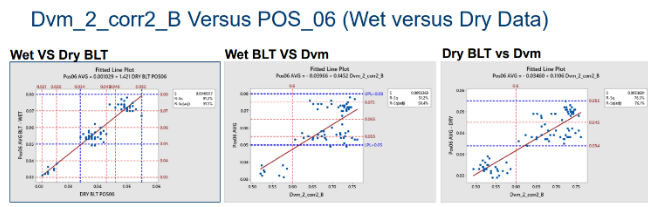


Fig. 4.4 Dvm_2_corr2_B Versus BLT

BLT Distribution and Optimizer suggests that optimized Overtravel distance of -0.1mm to -0.05mm as shown in Fig 4.5.

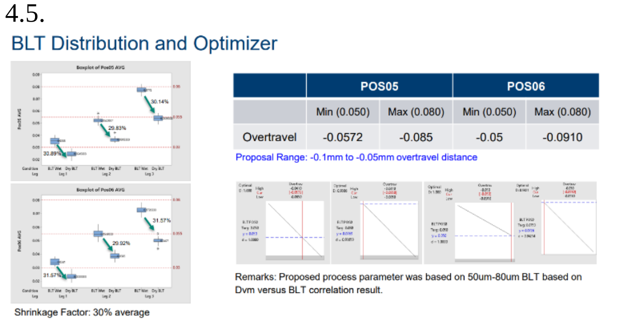
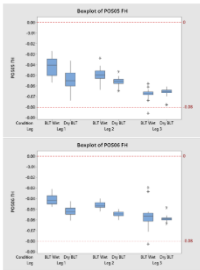


Fig 4.5 BLT Distribution and Optimizer

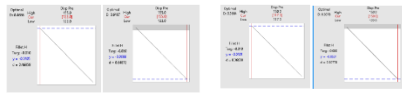
From Fig 4.6, Dispense pressure of 117-155KPa only covers the nominal range of -40um to -50um. Current set-up control is 0.0 to -80um which means the derived parameter can still be optimized or extended.

Fillet Height Distribution and Optimizer



	POS05		POS06	
(<0 to -80um)	Low	High	Low	High
Dispense Pressure	122	155	117	150

Proposal Range: 100KPa – 200KPa



Remarks: Proposed process parameter was based on <0um to -80um fillet height target.

Fig 4.6 Fillet Height distribution and optimizer

Proposed process parameter 100KPa – 200KPa in Fig 4.7 was based on <0um to -80um fillet height target projected in below model.

Dispense Pressure Versus Fillet Height

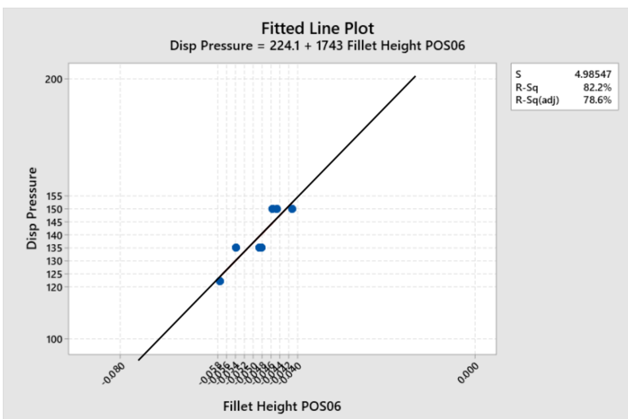


Fig 4.7 Fillet Height Versus Dispense Pressure

100% SCAT yield on low-mid-high BLT target.

Leg	Batch Number	Marking				X-RAY (Wire Sagging)				X-RAY (Flow Out)				CSAM				Status
		Qty In	Qty Out	Rejects	Yield	Qty In	Qty Out	Rejects	Yield	Qty In	Qty Out	Rejects	Yield	Qty In	Qty Out	Rejects	Yield	
Leg1: Low BLT	PD2429004800	30	30	0	100.00%	30	30	0	100.00%	30	30	0	100.00%	30	30	0	100.00%	Done X-RAY and SCAT
Leg 2: Mid BLT	PD2429004700	100	100	0	100.00%	100	100	0	100.00%	100	100	0	100.00%	100	100	0	100.00%	Done X-RAY and SCAT
Leg 3: High BLT	PD2429004600	98	96	2	97.96%	96	96	0	100.00%	96	96	0	100.00%	96	96	0	100.00%	Done X-RAY and SCAT

Fig 4.8 SCAT Summary

All BLT window legs (low-mid-high) met the reliability requirements as shown on Fig 4.9. Dvm shift trend is downward (this is the ideal result as it shows improvement in Dvm parameter). No delamination until the final readpoint.

Summary of Result:

Device Name	Reliability		Lot number	Test Response		Final Result
				SCAT	TEST (rej/ss)	
C4H18F700AV	TMCL (-65°C/+150°C w/ MSL3Acc + 3x reflow 245°C precon) ; req'mt = 500c	Low BLT	PD2429004800	No delam until 500c TMCL	100% Test yield (0/28) until 500c TMCL	PASS
		Mid BLT	PD2429004700	No delam until 500c TMCL	100% Test yield (0/30) until 500c TMCL	PASS
		High BLT	PD2429004600	No delam until 500c TMCL	96.67% Test yield (1*/30); *1-IGSO SN(52) - not related to DB	PASS*
	UHAST (130°C/85%RH/2atm w/ MSL3Acc + 3x reflow 245°C precon); req'mt = 96hrs	Mid BLT	PD2429004700	No delam until 192hrs UHAST	100% Test yield (0/30) until 192hrs UHAST	PASS
		High BLT	PD2429004600	No delam until 192hrs UHAST	100% Test yield (0/30) until 192hrs UHAST	PASS
	HTSL (175°C); req'mt = 1008hrs	Mid BLT	PD2429004700	No delam until 504H	96.67% Test yield (1*/30); *1-Idsv150V3 not related to DB	PASS
		High BLT	PD2429004600	No delam until 504H	96.67% Test yield (1*/30); *1-Igso - not related to DB	PASS

All the defined BLT window PASS 500c TMCL,192hrs UHAST, and 504hrs HTSL* with zero delam and decreasing Dvm trend (Dvm shift <10%).

*1 unit with 0-hr void that slightly increase after 504hrs but did not affect the Dvm shift.

Fig 4.9 C4H18F700AV Die Bond Window Trial Evaluation Reliability Result

From Fig 4.10 The proposed optimized parameters as below with passing bond line thickness, fillet and flow-out. BLT target is 65±10um.

o Overtravel Distance: -0.1mm to -0.05mm
o Delay: 200ms
o Dispense Pressure: 100KPa – 200Kpa

Date/Shift	Machine	Overtravel (POS05 / POS06)	Pressure (POS05 / POS06)	BLT (POS05 / POS06)	Fillet Height (POS05 / POS06)
7/26A Change Epoxy	DTN010	-0.075 / -0.08	154 / 145	0.070 / 0.063	-0.054 / -0.038
7/29B Change Epoxy	DTN010	-0.075 / -0.08	131 / 128	0.069 / 0.063	-0.038 / -0.033
7/30A Change Epoxy	DTN010	-0.075 / -0.08	125 / 119	0.067 / 0.062	-0.058 / -0.054
7/31A Change Epoxy	DTN010	-0.075 / -0.08	110 / 108	0.069 / 0.069	-0.051 / -0.054
8/1A Change Epoxy	DTN010	-0.075 / -0.08	135 / 132	0.069 / 0.064	-0.039 / -0.035
8/2A Change Epoxy	DTN010	-0.075 / -0.08	140 / 135	0.064 / 0.065	-0.029 / -0.026

Fig 4.10 Validation Result

5.0 CONCLUSION

The tailored full factorial DOE for bond line thickness (BLT) revealed that DVM is more strongly correlated with BLT, with an R-squared of 90.3%, compared to flow-out and fillet height, and showed no significant interaction between factors. With a p-value <0.05, overtravel was found to be a significant parameter influencing BLT in the DOE analysis, highlighting its crucial role in process optimization. It was demonstrated that raising the target BLT to 65±10μm improved die attach ruggedness without sacrificing DVM limits by modifying the DOE parameters. The DOE yielded the optimal process parameters, which include a dispense pressure between 100KPa and 200KPa, a delay of 200ms, and an overtravel distance between -0.1mm and -0.05mm. By ensuring that all tested units passed the stringent reliability screenings—500°C TMCL, 192 hours UHAST, and 504 hours HTSL—with zero delamination and less than 10% DVM shift, these DOE-validated settings demonstrated the efficacy of the customized DOE approach in creating a reliable, high-yield bond line thickness process.

6.0 RECOMMENDATIONS

To identify and fix possible deviations before they become time zero defects and guarantee product quality and dependability from the start, it is essential to prioritize process control monitoring in the early stages of development. Systematic evaluation of process variables, identification of optimal parameter sets, and comprehension of process robustness are made possible by the application of structured approaches to process optimization, such as Design of Experiments (DOE) and statistical process control (SPC).

This methodical approach enables the selection of the best alternative process conditions that maximize yield and performance without sacrificing quality or reliability. By continuously monitoring key metrics and integrating feedback loops, manufacturers can proactively prevent defects, minimize rework, and establish a resilient manufacturing process that adapts to variations, ultimately reducing the risk of early-stage failures and supporting consistent delivery of high-quality semiconductor products.

By incorporating these lessons into the overall process design and continuously monitoring and improving the manufacturing process, it is possible to minimize quality excursions and ensure the reliable production of semiconductors.

7.0 ACKNOWLEDGMENT

The authors would like to thank the AMP management team for making the project possible, and Jantzen Bobares, Director and Project Manager for supporting and providing technical guidance.

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3. Energy & Eco-Sustainability using Pressure-less Silver Sintering for RF Power Electronics Authors: Evan A. Hueners, Richard D. Hueners, Anthony D. F. O'Sullivan, M. Redzuan Zin.
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